

Gerard T. van Belle
Jet Propulsion Laboratory

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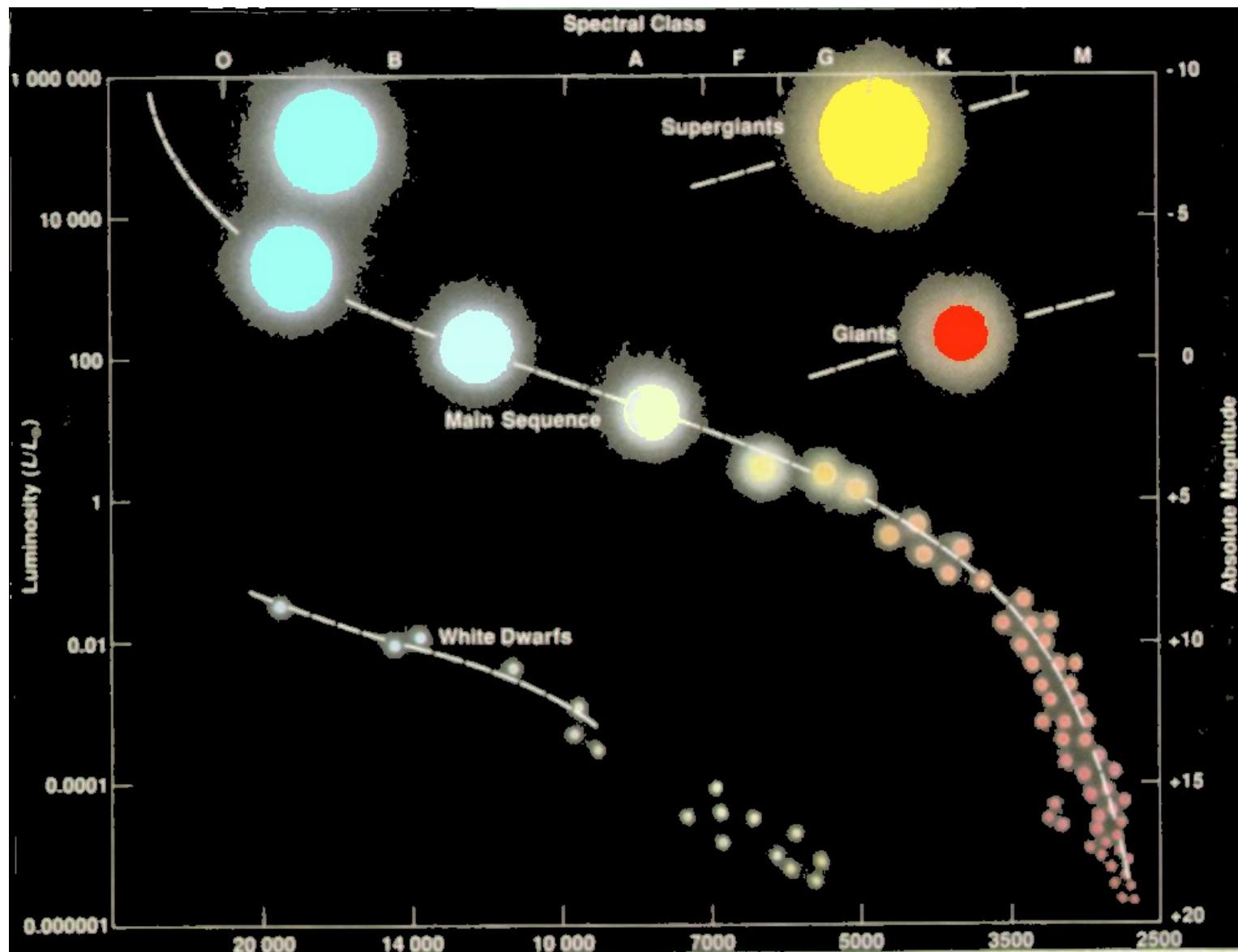
History of Angular Diameter Measurement

- Michelson & Pease
- Narrabri - intensity interferometry
- Lunar occultations
- Amplitude interferometry
 - Mark III, IOTA
 - NPOI, PTI

Basic Parameters from Angular Diameters (θ)

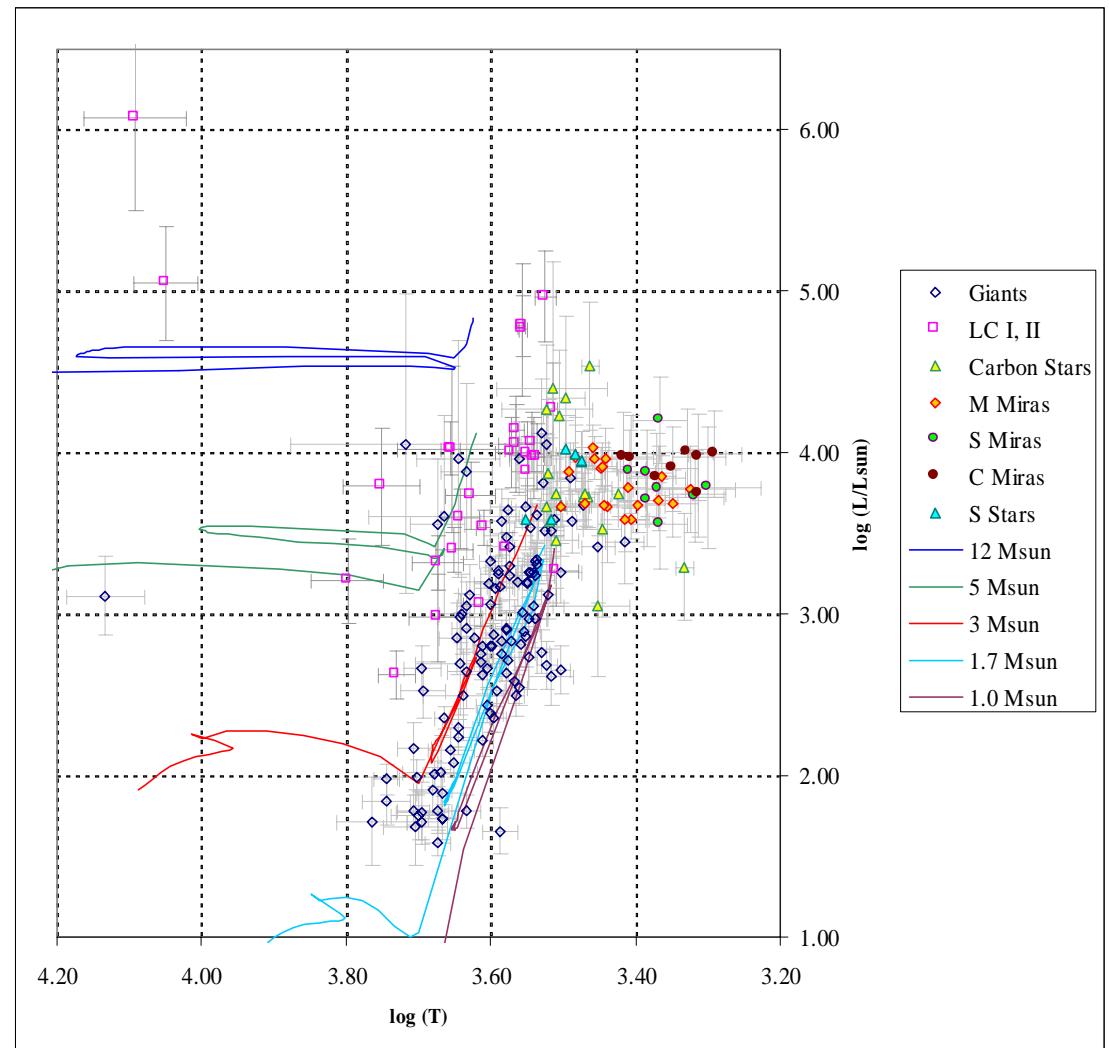
- Effective temperature is defined as: $L = 4\pi\sigma R^2 T_{\text{EFF}}^4$,
which can be rewritten as: $T_{\text{EFF}} = 1.316 \times 10^7 \left(\frac{F_{\text{BOL}}}{\theta_{\text{R}}^2} \right)^{1/4}$
 - F_{BOL} is the bolometric flux (W cm^{-2}), θ_{R} is the Rosseland mean stellar angular diameter (mas)
- Linear radius is simply: $R = \frac{1}{2}\theta \times d$
 - Hipparcos (Perryman et al. 1997) distances now available
 - Uncertainties in parallax (typically $\sim 15\text{-}20\%$) still largest contribution to error

HR Diagram. I



HR Diagram. II

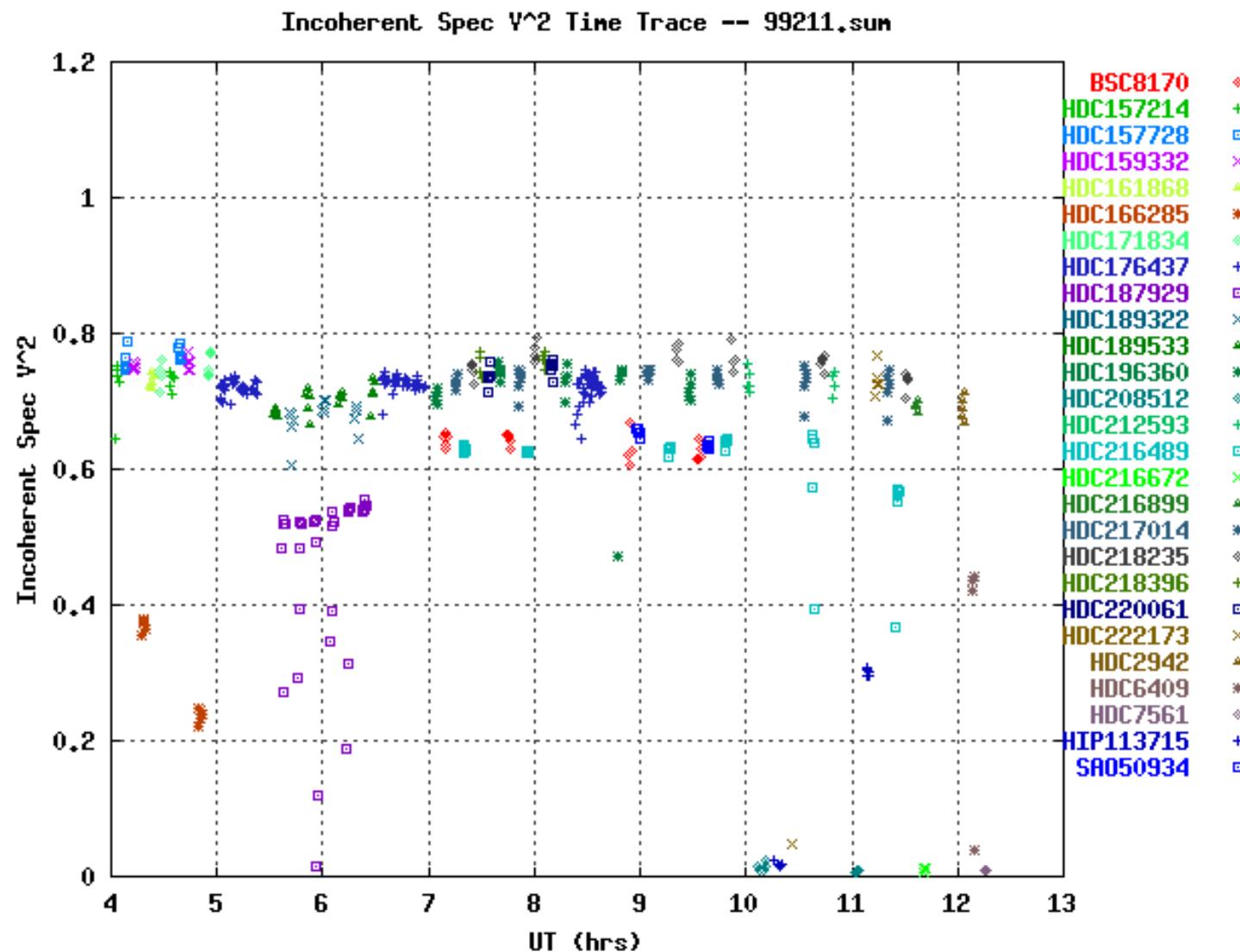
- Key tool in understanding life cycles of star
- Model Tracks:
 - All tracks are $Z=0.02$ (solar)
 - Tracks from 1.0 - 12 solar masses
(Schaller *et al.* 1992,
Charbonnel *et al.*
1996)



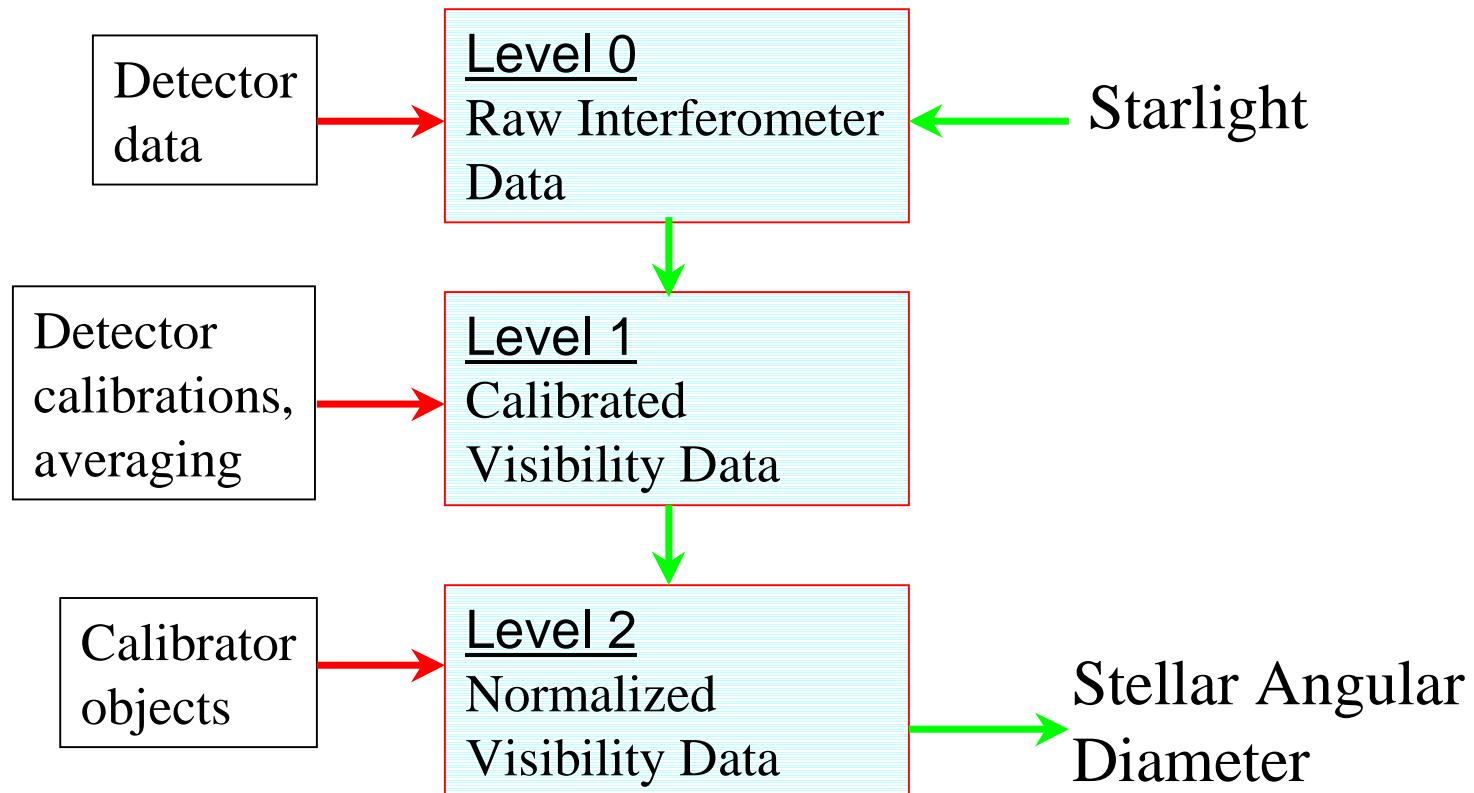
Ancillary Data

- Visibility data largely impotent without it
- Photometry
 - Contemporaneous data important for variable stars
- Distances
 - note size vs. parallax problem
- Spectroscopy
- Radial velocity data

Visibility Data from an Interferometer

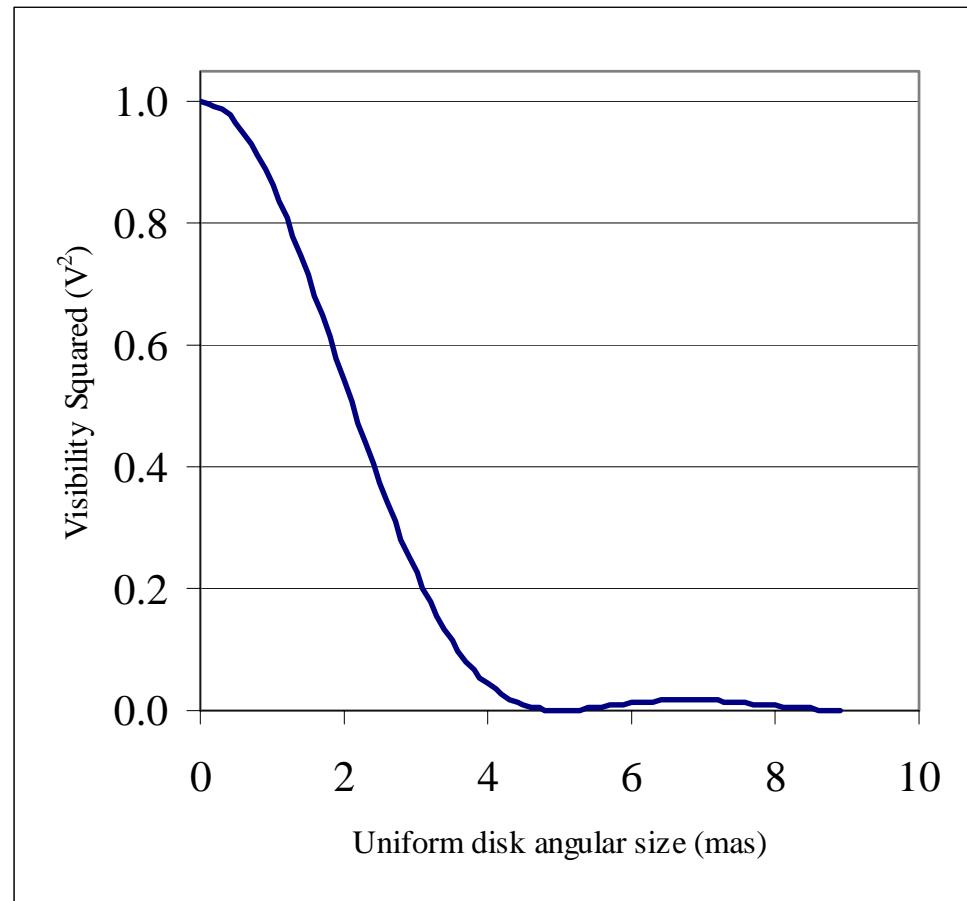


Visibility Data Reduction



Uniform Disk Diameters from Visibilities

- Solve for uniform disk diameter θ_{UD}
 - Use $V^2 = (2J_1(x)/x)^2$ in central lobe;
 $x = \pi\theta_{UD}B_p/\lambda$
- Assumes source is a top hat



Conventions and Caveats

- Angular *diameters* typically given, in contrast to linear *radii* (watch that factor of 2!)
- Luminosity is not defined by θ
 - Luminosity goes as $L \sim R^2 T^4 \sim d^2 F_{BOL}$
 - Limits HR diagrams

Current Stock of Results

- Borrowing from Davis (1997), increase of 145 to 340 stars in the literature
 - Largely due to sizes published by Dyck & van Belle
 - Noting that 78 of the original 145 are still unpublished
- Notable improvement: Application of interferometry to evolved stars
- Notable area for improvement: *Still* main sequence stars, particularly late-type

Spectral Type	I	II	III	IV	V
O	3	0	0	0	1
B0-B4	2	2	3	2	2
B5-B8	2	0	2	1	1
A0-A3	1	0	0	2	5
A5-A7	0	0	1	0	1
F0-F5	4	1	0	1	0
F8	2	0	0	0	0
G0-G5	3	1	2	3	0
G7-G9.5	2	1	22	0	0
K0-K3.5	5	16	31	0	0
K4-K7	3	1	14	0	0
M0-M4	12	13	70	0	0
M5-M8	1	2	31	0	0
Totals	40	37	176	9	10

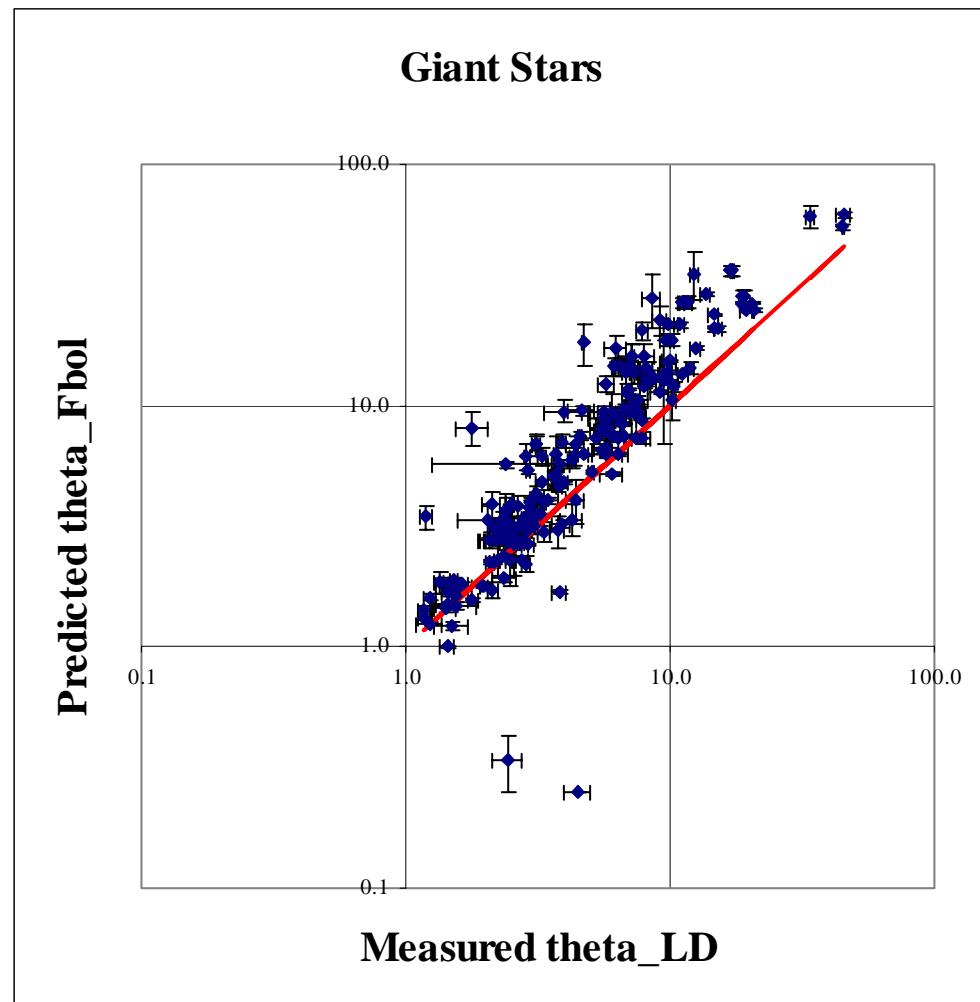
Evolved Stars	
Carbon	22
M Miras	37
C Miras	5
S Miras	4
Total	68

Calibrator Objects

- Need to establish instrument point-source response
- Chicken & the egg
 - Need to predict sizes to measure sizes

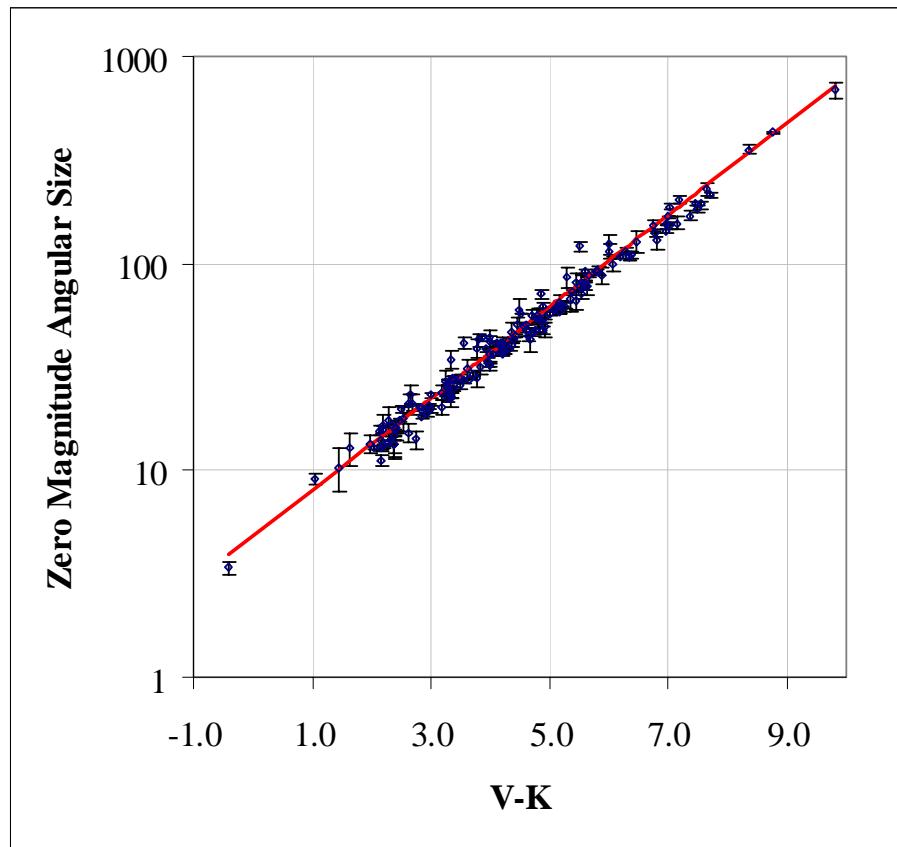
Prediction of Stellar Angular Sizes. I.

- Linear radius - distance
 - Radius vs. V-K
 - Distances hard to come by
- BBR assumptions
 - Systematic differences



Prediction of Stellar Angular Sizes. II

- Define a zero magnitude angular size
- Unaffected by Interstellar reddening
- Uses only V, K magnitudes; accurate to 11-12%
- Error sources
 - Angular size errors
 - V-K errors
 - Unparameterized phenomena – ‘natural dispersion’
- van Belle (1999)



Uniform Disk vs. Limb-Darkened Diameters

- quote Hajian NPOI paper

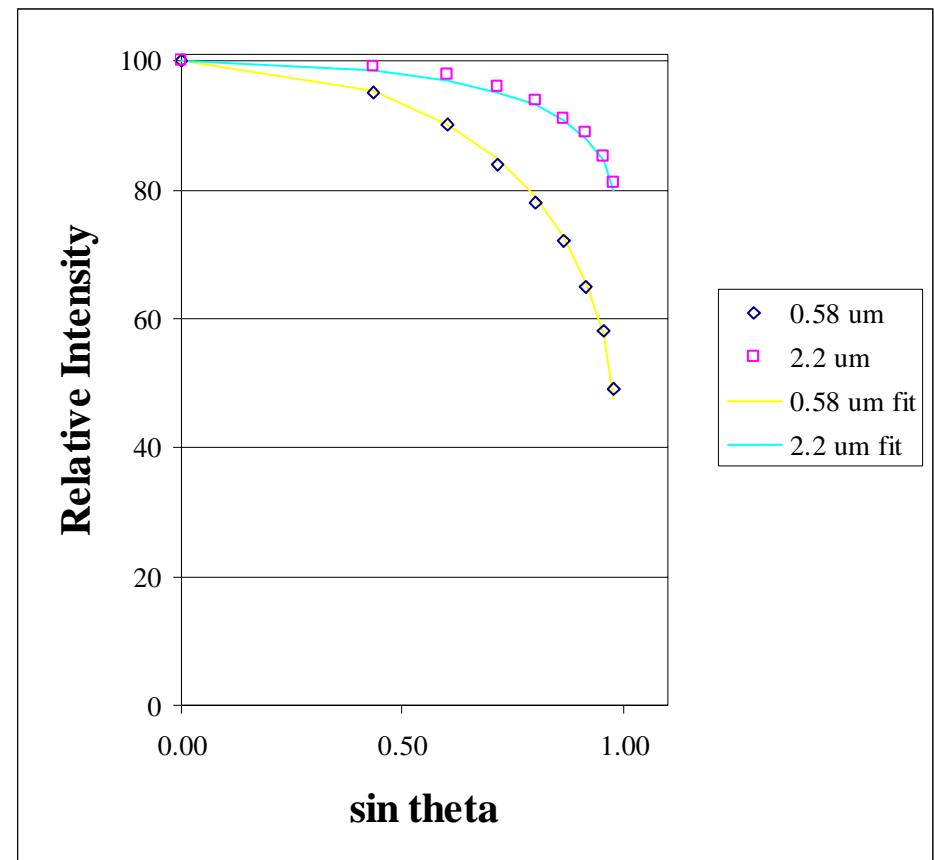
Uniform Disk vs. Limb-Darkened Diameters

- Solar values: Pierce & Waddell (1961)

- Fit law

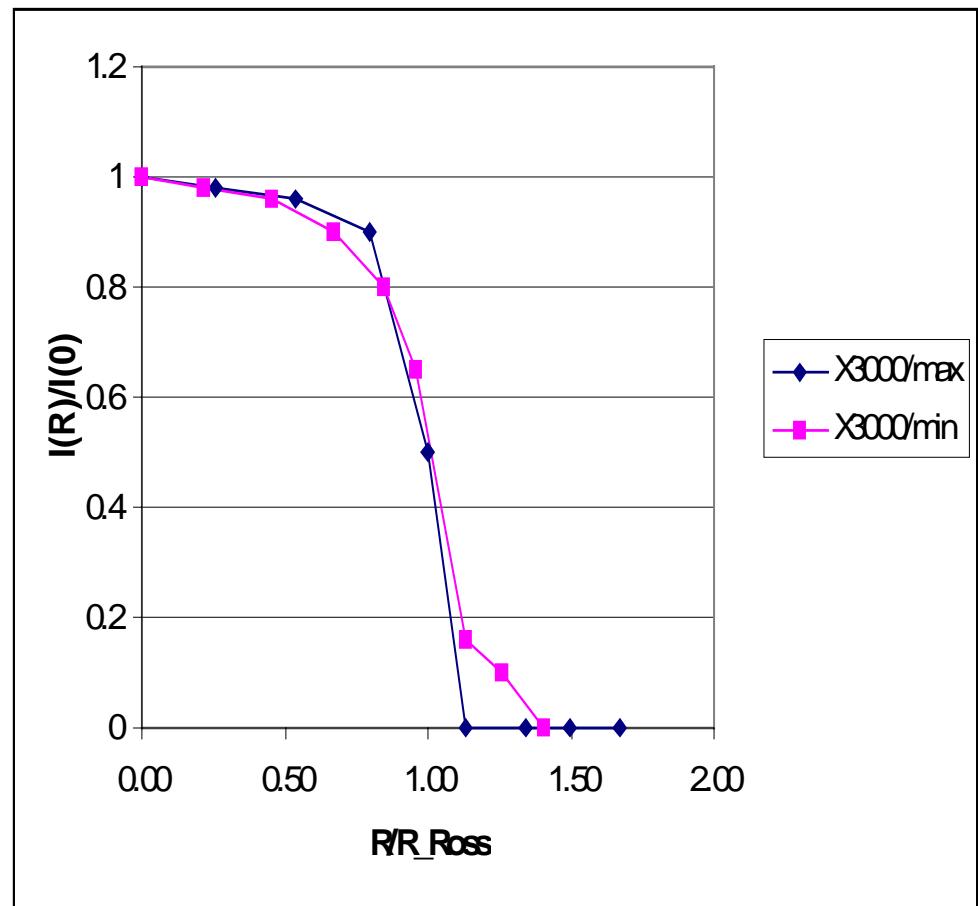
$$I(\theta)/I(0) = (1 - \sin^2 \theta)^n$$

- $n(0.58\text{um})=0.23$,
 $n(2.2\text{um})=0.07$



Model Center-to-Limb Predictions

- Good example:
Scholz & Takeda
1987
 - Can compare θ_{UD} to θ_{ST}
 - 3000K max light model: 0.99
 - 3000K min light model: 1.17
- Very separate effects for 3500K models,
 $Z=nonsolar$, etc.



Higher Order Surface Structure

- Hot/cool spots
- Nonsphericity
 - Evidence from Monnier et al (1999) and Tuthill et al (1999) of asymmetries in stellar envelopes

Wavelength Dependent Effects

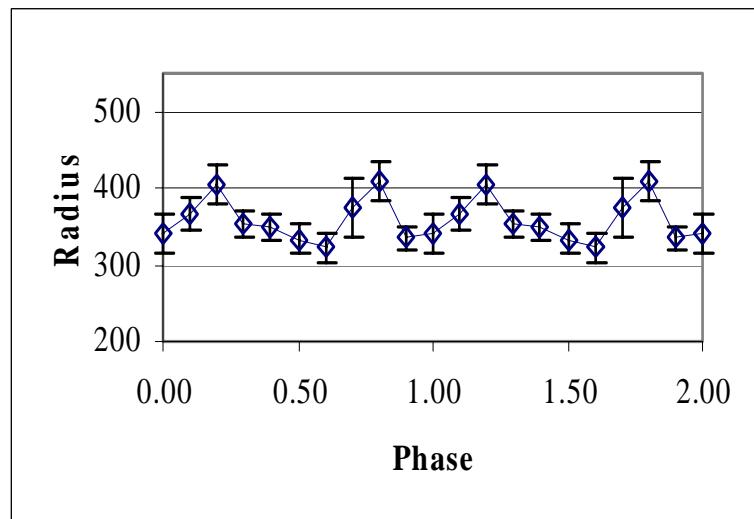
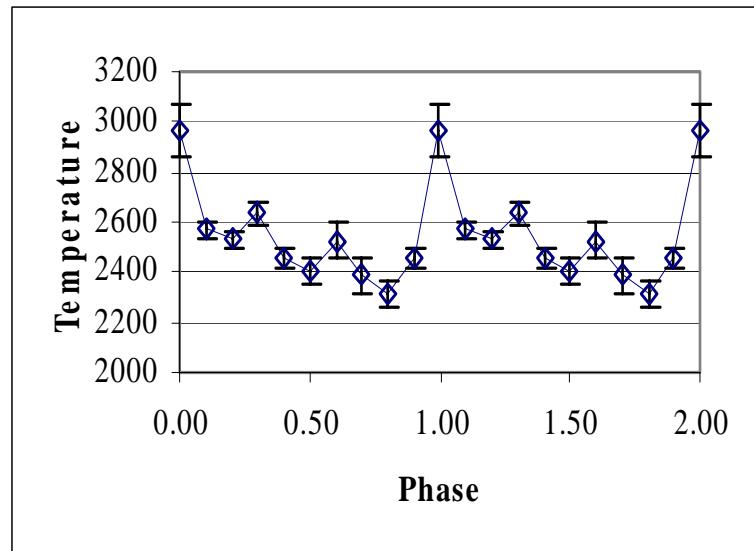
- Molecular absorption bandheads
 - K band: CO (2-0) at TBD
 - Red: TiO at TBD

Temporal Effects

- Progression of T, R with phase for variable stars
 - Mira variables
 - Cepheid variables
 - Semi-regulars
- Best single star results: COAST (see Haniff et al. 1999) TBD***
- Forthcoming IOTA results (see Milan-Gabet et al. 2000?)

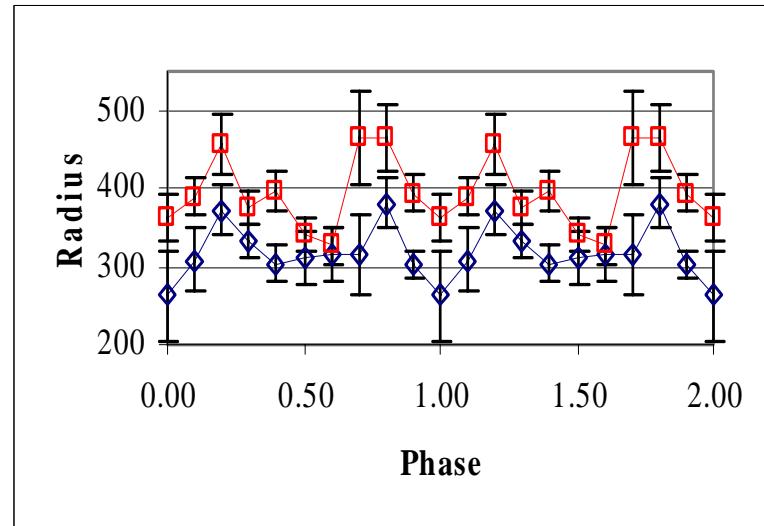
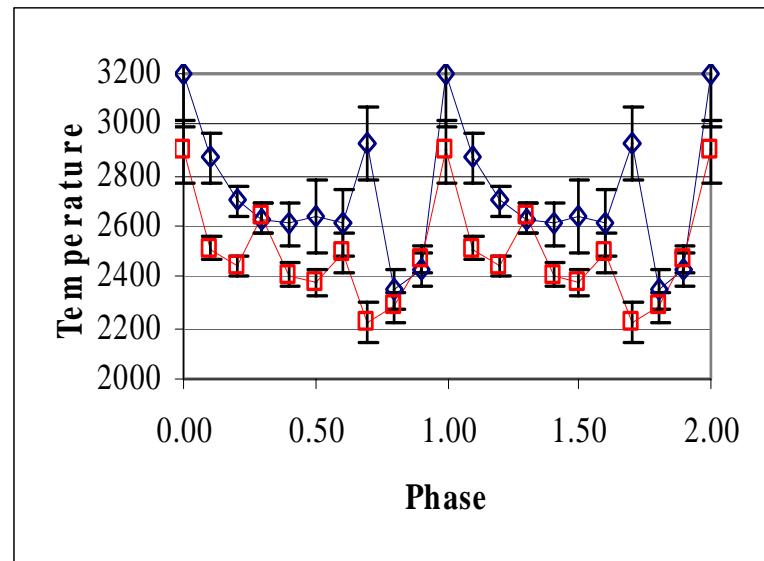
Mira Variables: T , R Versus Phase

- Zero-phase corresponds to maximum light as determined from V band photometry
 - Maximum T , R minima
 - Also thought to correspond to the star expanding through its equilibrium radius with maximum velocity (Kanbur et al. 1997)
- Second R minima seen at $\phi \sim 0.6$ - possible explanations:
 - Dissimilar Miras in sample set
 - Observation of separate atmospheric layers (eg. shells?) and/or shocks



T, R vs. Phase: Short vs. Long P Miras

- Data set separated into ‘short’ ($P < 350$ d, blue) and ‘long’ ($P > 350$ d, red) period Miras
- Consistent temperature, radius differences
 - $T_{350+} / T_{350-} = 0.93 \pm 0.01$
 - $R_{350+} / R_{350-} = 1.20 \pm 0.05$
- Indicates $L_{350+} / L_{350-} = 1.07$
 - Consistent with longer-period Miras being more evolved, more luminous objects
- Double-peaked structure still evident in R vs. ϕ



Pitfalls in the Esoteric Art

- Binarity
- Combination of resolution / sensitivity / calibration
 - Example: PTI
 - Rule of thumb

Future Directions

- Easily extended to non-stellar objects